Staff Analysis on Emissions and Economic Impacts of Regulatory Proposals for DIY Recharging of Motor Vehicle Air Conditioners Using Small Cans

PREFACE

Do-it-yourself (DIY) recharging of motor vehicle air conditioning systems (MVACs) with HFC-134a generates emissions of about 0.71 $MMTCO_2E$ annually. This document presents an analysis of four proposals for reducing those emissions. ARB's original Can Ban proposal would reduce emissions by 0.47 $MMTCO_2E$ per year, which is about 66% of emissions from this source, at an average cost of about $135/$MTCO_2E$ to the consumer and about $25 million per year in lost revenues to the DIY can industry. An alternative proposal put forth by industry is estimated by staff to reduce emissions by 0.19 $MMTCO_2E$ per year, or 31% of emissions from this source, at a cost of about $19/$MTCO_2E$ to the consumer. A third approach enhances the industry proposal by adding a mandatory return and recycling program for the cans, setting a target can return rate of 95%, and establishing a comprehensive DIY education program. It could achieve emission reductions of 0.22 $MMTCO_2E$ per year. The increased cost is $2 million per year and the cost-effectiveness works out to be $9/$MTCO_2E$. A fourth proposal being considered would reduce DIY emissions by using mitigation fees to reduce emissions in this or other sectors. The mitigation fee approach could reduce 0.85 $MMTCO_2E$ per year (i.e., the total emissions associated with the use of small cans including DIY and professional). This reduction would cost about $25/$MTCO_2E$. This mitigation fee approach could also be combined with portions of the recycle based proposals.

INTRODUCTION

As required by AB32, the ARB has developed a list of early action measures (ARB, 2007a). Six of these early action measures are related to Motor Vehicle Air Conditioning (MVAC). According to the U.S. EPA Vintaging Model, MVAC systems are the dominant user/consumer of HFC-134a (Thundiyil, 2005). One of the early action measures, reduction of HFC-134a emissions from do-it-yourself (DIY) service of MVAC systems has been identified as a discrete early action. DIY servicing involves recharging the AC system using small cans of refrigerant typically containing about 12 ounces of refrigerant in weight, but ranging from 2 to 36 ounces in weight. The ARB proposed banning the sale and use of small cans. Industry proposed an alternative plan that they claim would achieve similar emission reductions at lower cost. In its June 2007 meeting, the Air Resources Board directed staff to evaluate recommendations for early actions made by a group of stakeholders, including the Environmental Justice Advisory Committee (EJAC). The EJAC recommended removing the proposed "Can Ban" measure from the Early Action list because the committee believed that the measure seemed unlikely to achieve the goal of detection and repair of leaking auto air conditioning systems, and because it would place a large burden on low-income people (EJAC, 2007). Those people are likely to disproportionately rely upon home-based auto repair and stop-gap repair options such as using the small cans of HFC-134a to fill leaking air conditioning units.

ARB staff has now explored impacts of adding firm recycling rate targets and a DIY education program to the industry proposal, and a fee-based approach that could be implemented stand-alone or in parallel with the recycle and education proposals. This paper compares emission reductions and costs associated with these four proposals. The reductions in emissions are calculated in terms of changes from business-as-usual (BAU). The following discussions provide an overview of the method to calculate emissions and costs, key data, key assumptions, and the results. Details of the calculation and results of alternative assumptions are provided in Appendix A.

METHODS

Business-As-Usual

Practice

DIY practice involves puncturing a one-way can of refrigerant with a low cost apparatus consisting of a valve and hose, connecting the apparatus to the low pressure (suction) side of the AC system, and transferring refrigerant from one or more small cans to the AC system over the course of many minutes. There are two immediate sources of emissions resulting from this process. First, some refrigerant escapes from the can and apparatus during the servicing process, which is called servicing leaks. Second, some of the refrigerant typically remains in the small can after the refilling process has been completed. This remainder is called the can heel. Because most cans do not include a means to close the can, the entire can heel is emitted to the atmosphere shortly after the can is disconnected from the recharge apparatus.

In addition to the immediate emission there is also a delayed emission that can be associated with DIY practice. The AC system that receives charge from the DIY small can has leaked, hence the need for recharge. Not all DIY service operations are necessarily on systems that leak more than properly functioning systems, but some DIY operators recharge their systems every few months. The information needed to determine the distribution of leak rates from DIY vehicles is not readily available. But because in most instances the DIY operator is not repairing the AC system, but simply re-filling the leaking system, the leak rate is very likely to be higher than properly repaired systems. The U.S. EPA Vintaging Model assumes that a properly functioning system should only need to be recharged after about 6 years (Thundiyil, 2007). The difference in leak rates between DIY serviced and professionally serviced systems is an emission that can be attributed to DIY practice. Professional service technicians are required to fully diagnose the AC system before repairing or recharging it. The majority of customers choose to make repairs, even though some choose to reject repairs and top off, and some choose to reject repairs and forgo air conditioning (Atkinson, 2008b).

Emissions

ARB's Survey of Consumer Products for 2006 estimates that California sales of HFC-134a in small containers are 654 metric tons in about 2 million cans (ARB, 2007b). Using a Global Warming Potential (GWP) of 1300 for HFC-134a (IPCC, 2007), the annual sales correspond to 0.85 million metric ton CO_2 equivalent ($MMTCO_2E$) per year. Based on information from a small can industry consortium (ARPI, 2008a), approximately 70% of small can sales are made to DIY individuals and 30% to commercial accounts. In contrast, based on a study by a MVAC trade association (MACS, 2008), only 4.6% of small cans sales are made to automotive repair shops, suggesting that 95.4% are used by DIY. For the purpose of this analysis we use the average value of 70% and 96.4%, or 83%, to represent the fraction of small can sales being used by DIY. This amounts to 0.71 $MMTCO_2E$ per year of HFC-134a being used by DIYers in California. The remaining 17% of small cans are assumed to go to professional AC shops. This analysis only considers small can operations performed by individual consumers as DIY emissions. We do not include emissions associated with small can use by professionals, nor do we include reductions of these emissions by the proposed mitigation measures.

The fraction of DIY can use apportioned to service loss, can heel, and system charge is estimated to be 11%, 22%, and 67% respectively. These figures are based on research commissioned by ARB (Clodic et al., 2007). The immediate emissions are thus approximately 0.23 $MMTCO_2E$ per year and the delayed emissions are approximately 0.48 $MMTCO_2E$ per year. The following figure illustrates the emissions associated with DIY practice.

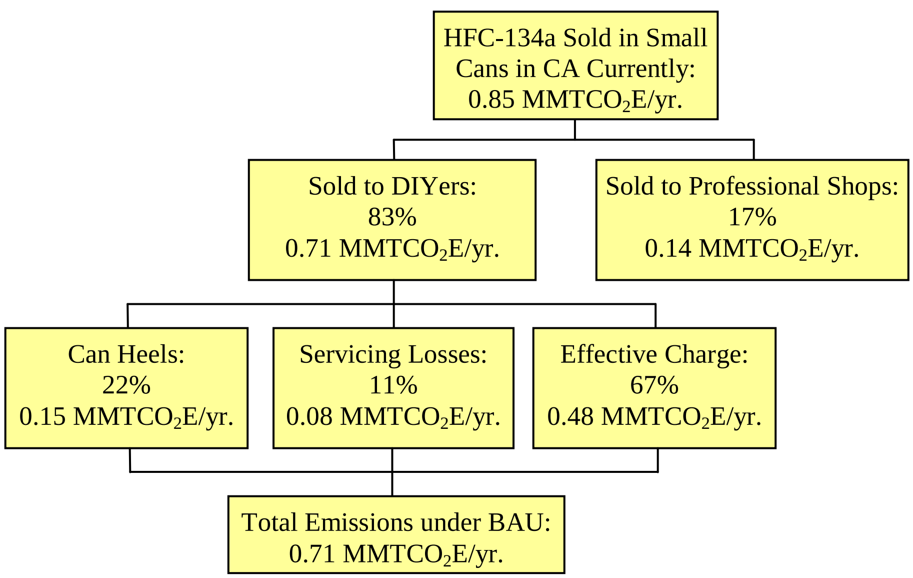

Figure 1. HFC-134a Emissions under Business-as-Usual DIY Small Can Practice

Costs

The annual consumer cost associated with BAU is based on the average retail cost per can. Based on the NPD Automotive Aftermarket Industry Monitor Data from the total U.S. auto parts chain retailers sales records (NPD, 2008), the cost average out to about $13 per can, including the cost of the transfer apparatus.

To estimate lifetime costs and costs per consumer, it is necessary to estimate vehicle life and the rate at which the vehicle needs service. Based on a study carried out by ARB staff for the purposes of AC servicing (Vincent et al., 2004), the average vehicle lifetime in California is 16 years. Based on the I-MAC study (I-MAC Team, 2007), the average time for which a new vehicle will not need service is about 7 years. This is also consistent with ARB's study (Vincent et al., 2004). The estimated portion of time for which an average vehicle needs servicing is then 9 years. For vehicles receiving professional service, the system is assumed to be made nominally leak free and it is estimated to need service at approximately 6 year intervals (Thundiyil, 2007). For vehicles receiving DIY service, it is assumed that the leaks are not repaired, and it is estimated that the vehicle is recharged about once per year, primarily during summer, based on a survey conducted by ARB staff. Some DIY use small cans containing "stop leak" compounds, but the percentage of such users is small and the effectiveness of such compounds are not certain. For the current analysis we assume that the leaks are unrepaired and that the DIY service rate of 1 service per year based on various data sources, which generates 9 DIY services over the 9 years of service need.

To estimate costs per consumer, it is necessary to estimate the number of vehicles needing service. The ARB study data indicates that the average number of cans used per service is 1.3 (Clodic et al., 2007). Given that 1.6 million cans per year are used by DIY operators, about 1.2 million DIY service operations occur each year. Given a DIY service rate of 1 per year per vehicle, the number of individual vehicles receiving DIY service is 1.2 million. At 1.3 cans per service and about $13 per can, the average cost of one DIY service is about $17. The cost per vehicle per year is then about $17. The annual cost to consumers for 1.6 million cans at about $13 each is $21 million per year. The cost of 9 DIY service operations over the life of the vehicle is about $152.

Can Ban

Practice

ARB's staff proposed to ban the sale of small cans. Ideally, there would no longer be any DIY servicing. All servicing would be done by professional shops. Some consumers would forgo air conditioning and some would take their vehicle to the professional shops. In practice, some DIYers will evade the regulations and acquire HFC-134a for DIY operations. This behavior is called "leakage". Professional shops in California are required to conduct complete diagnostics. Based on trade association survey data most vehicles brought to a professional shop are repaired before being released in a recharged state. The repairs conducted by professional shops are expected to last six years, thus reducing the emission rate for former DIY vehicles to one sixth of its pre-repair value. During professional repair and recharge, a certain amount of refrigerant will be emitted due to servicing losses and can (cylinder) heel emissions. There will also be some professionally serviced vehicles that may need repairs but receive a recharge only, i.e. a top off. There will also be professional serviced vehicles for which repairs are not effective. For purpose of analysis these vehicles are considered part of the group of vehicles that receive a professional recharge service (top off) without repair.

Emissions

Under the ban, the treatment of the delayed emissions of 0.48 $MMTCO_2E$ per year from leaking vehicles is divided into categories based on consumer choices. The emission reductions are different for each category. A Frost and Sullivan study of small can consumers commissioned by the ARPI estimates that 12% of former DIY owners would opt to have no air conditioning rather than go to a professional shop, 49% would go to the professional shop, and 39% would look for other options of obtaining refrigerant (Frost and Sullivan, 2006). The 39% of consumers seeking alternative options will contribute to "leakage", but it is unlikely that all of them will have the perseverance to circumvent the small can ban regulations. The true leakage rate will probably be somewhere between 0% and 39%. In the absence of further data on which to assign a leakage rate, we currently assume the midpoint of this range, or 20% will obtain HFC-134a by alternative means. We assume that the remainder of those looking for alternative sources of HFC-134a will eventually choose one of the legitimate options which are: obtain professional repairs, obtain professional top off, or forgo air conditioning. We assign that remaining 19% of the former DIYers equally among the three legitimate options: 6% forgo air conditioning, 7% go to the shop for diagnosis and repairs, 6% go to the shop for top off. The percentages in each category become: forgo air conditioning 12% + 6% = 18%; go to the professional shop for diagnosis and repairs 49% + 7% = 56%; go to the professional shop with the specific objective of having their system topped off, 6% + 0% = 6%; and obtain HFC-134a by alternative means 20% + 0% = 20%.

A 2005 MACS study showed the choices of customers who currently visit professional shops for diagnosis and repair (Atkinson, 2008b). The study surveyed 7 service facilities located in Pennsylvania, Ohio, Arizona, California and Florida and included over 1,400 repair orders. In that study, among those with refrigeration circuit problems, 5.1% choose to reject repairs and forgo air conditioning, 6.8% chose to reject repairs and be topped off, and 88.1% chose to have their system repaired. When the 56% of consumers described in the preceding paragraph who go to professional shops for diagnosis and repair are reapportioned into those three categories, the following overall proportions are obtained: 21% of current DIY consumers forgo air conditioning, 10% reject repairs and have their system topped off, 49% have their system professionally repaired, and 20% obtain HFC-134a by alternative means (leakage). The figure below shows how the various fractions were apportioned and recombined, with the final values on the right.

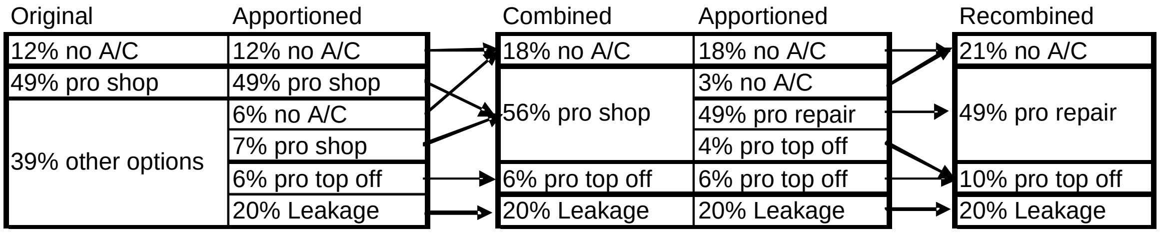

Figure 2. DIY Behavior Change under Can Ban

The 21% of vehicles that receive no top off and no repair are assumed to become empty and no longer emit refrigerant. Therefore 0.1 $MMTCO_2E$ of refrigerant emissions per year are reduced to zero. (Forgoing MVAC has potential consequences for indirect emissions because consumers without A/C would likely drive with windows rolled down for a large share of VMT. The increased load due to increased drag force must be balanced against the reduced load due to non-operation of the AC compressor. At high speed, indirect emissions might be increased. At low speed, indirect emissions will be reduced. On average, the change in indirect emissions due to non-operation of the MVAC is expected to be a net reduction (i.e., forgoing A/C would probably reduce indirect emissions). Changes in indirect emissions have not been included in the analysis.

The 10% of vehicles that are topped off are assumed to emit at their original rate. Therefore, the 0.05 $MMTCO_2E$ of refrigerant per year emitted by these vehicles remains the same.

The 49% of vehicles that receive professional repair are assumed to have their original leak rate of one charge per year reduced to one charge per six years. Therefore, 0.24 $MMTCO_2E$ per year are reduced to 0.04 $MMTCO_2E$ per year. The total delayed emissions from the leaking vehicles that receive professional servicing are then 0.09 $MMTCO_2E$ per year.

Although the service loss and can heel due to DIY operations has been eliminated, professional operations also have service and can heel losses. Based on assumptions in the GREEN-MAC-LCCP model, servicing losses are assumed to be 10% of the effective charge (nominal charge minus the amount in the A/C when it is brought in the shop) and can heel losses are assumed to be 2%. It should be noted that some assumptions in the GREEN-MAC-LCCP model include these servicing losses are still under peer review. So the estimated percentages may be modified if the assumed values are updated. To achieve an effective charge of 0.09 $MMTCO_2E$ per year, professionals would actually consume 0.10 $MMTCO_2E$ per year: 0.05 to top off leaking systems, 0.04 to replace the gradual leak of properly serviced vehicles, and 0.01 in service loss and can heel.

The 20% of vehicles that continue DIY recharge through alterative means (leakage) are assumed to emit at their original rate, including can heel and servicing loss. Therefore, the 0.14 $MMTCO_2E$ of refrigerant per year emitted by these vehicles remains the same.

Total annual emissions under the ARB proposal are thus 0.24 $MMTCO_2E$. The annual emission reductions are 0.71 minus 0.24, or 0.47 $MMTCO_2E$ (Figure 3).

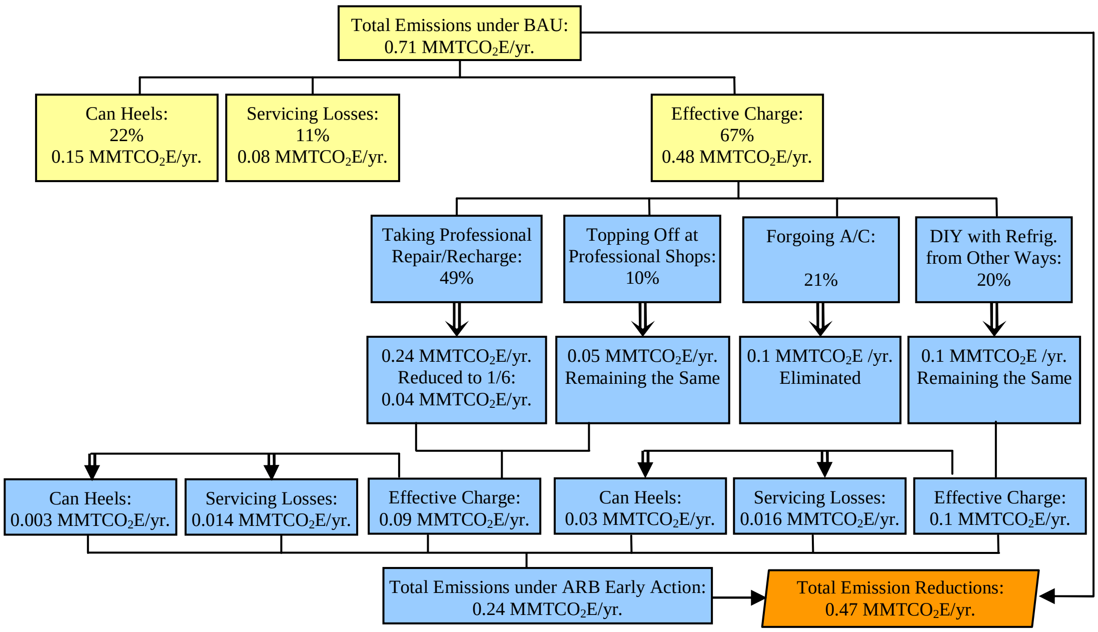

Figure 3. HFC-134a Emissions under Can Ban Approach

<u>Costs</u>

There would be no costs or charges imposed on the small can industry to comply with the ban, but there would be complete loss of revenues from the small can business in California. Annual can sales to DIY owners are about 1.6 million at an average retail price of about $13 including cost of transfer apparatus. The 0.3 million cans sold to professional AC shops are also assumed to be at $13 per can for purpose of analysis. Therefore, industry would lose annual revenues of about $25 million due to the small can ban.

Under the small can ban, consumer costs would be affected by the difference between the cost of professional repairs and the cost of DIY recharges. DIY recharges were estimated to occur at a rate of one per year, at cost of about $17 per year. Professional diagnosis/repairs/recharges are estimated to cost about $650. This is based on MACS 2003 Survey which shows that a professional repair cost $508 on average in 2003 (MACS, 2008), which is about $580 in 2007 dollars. We then add $70 recharge charge on top of that. Professional repair/recharge is assumed to occur every 6 years on average for a cost of $108 per year for the 49% of consumers choosing professional repair. Professional topping off is estimated to cost about $100 (Clodic et al., 2008), and to occur once a year on average for a cost of $100 per year for the 10% of consumers choosing to have their system topped off. About 20% of consumers would still DIY recharge their leaky vehicles once a year using refrigerant that they obtain from alternative ways, at a cost assumed to be 50% higher than under BAU, or about $25 per year. For the approximately 1.2 million vehicles involved, the total consumer cost increases from $21 million to $84 million, an increase of $63 million annually. For individual owners, the vehicle lifetime cost increases from $152 for 9 DIY services over the life of the vehicle to $975 for 1.5 services over the life of the vehicle for owners choosing repairs, increases to $900 for 9 top offs during the life of the vehicle for owners choosing professional top off, and increases to $228 for 9 DIY recharges over the life of the vehicle for owners finding HFC-134a by alternative means. In addition about 21% of consumers do not pay the increased cost, and therefore have no air conditioning in their vehicles. The average lifetime cost for a DIY vehicle is then $613.

Under the small can ban, the professional vehicle A/C repair industry would see a revenue increase equal to the amount paid by former DIY operators to obtain professional repairs. This amount is estimated to be $77 million per year.

Cost-Effectiveness

Cost-effectiveness under this proposal is calculated here using only the increased costs to consumers and the revenues lost to the small can industry from retail sales in California. It does not consider the gains made by professional A/C repair operations.

The emissions reduction under the can ban proposal is 0.47 $MMTCO_2E$ per year. The increase in consumer cost is $63 million per year. The cost per metric ton of reduction borne by the consumer is then about $135/$MTCO_2E$. The lost revenues are about $25 million per year.

Industry Proposal

Practice

The industry has proposed an alternative plan with three components (ARPI, 2008b):

- One, small cans will be fitted with a valve that will reduce losses during DIY service and will eliminate loss of the can heel after DIY service.
- Two, the instructions on the can will be improved to reduce losses during service and to reduce the size of the can heel.
- Three, ARB will establish mandatory requirements to recycle small cans and recover the can heels, the industry will establish a program to implement the can recycle and recovery requirements.

In addition, the industry would support efforts to include new A/C inspection and repair requirements into the smog check program.

Consumers would be required to pay a deposit on each can of HFC-134a that they purchased, and would receive a refund of the deposit when they returned the can to its place of purchase. The small can producers would receive the cans back from the retailers, recover the can heel, and recycle the small can as scrap metal. The details of the recycle program such as financial obligations of participating packagers and retailers, recycle locations, recycle rate reporting obligations, etc. have not yet been provided to staff. The industry is confident that a workable program can be put in place based on the following considerations. Consumers are familiar with deposit programs. Retailers in the automotive supply business are familiar with recycle programs such as for used oil, with core deposit programs for return of items such as batteries and alternators, and with returns of defective products. Industry is confident that automotive retailers would likely comply with recycling requirements if the alternative were to forgo small can sales. Small can producers can use their existing production line equipment with only minor modification and little capital investment to conduct the can heel recovery process. The return rates would depend on the magnitude of the deposit and on the success of consumer education programs. Industry is now proposing a deposit of $5 per can.

<u>Emissions</u>

The combination of a can valve and new instructions may significantly reduce losses during service. For the purpose of evaluating the industry proposal we assume that service loss emissions are reduced from 11% of can contents to 1%. This percentage is defined in relation to the total emissions under BAU for calculation convenience. This is an emission reduction from 0.08 MMTCO_2E per year to 0.007, for a net reduction of 0.07 MMTCO_2E.

Effective use of the new valve would eliminate emissions from the can heel, provided the cans were returned for recycle. Industry expects a participation rate over 90%. It is now conducting a pilot program to test the return rate. For the purpose of this analysis we assume a return rate of 75% based on the preliminary result from the pilot study. The can heel from recycled cans is assumed to be captured with 100% efficiency. All of the can heel from unrecycled cans is assumed to eventually reach the atmosphere. The current emissions from the can heel are estimated to be 0.16 MMTCO_2E per year. At a 75% recovery rate this would be reduced to 0.04 MMTCO_2E per year, for a net reduction of 0.12 MMTCO_2E per year.

The ARB has proposed a measure to incorporate A/C testing and repair into the California smog check program as an Early Action (ARB, 2008g). The industry proposal works best in conjunction with an A/C smog check program, and industry supports that early action measure. However, a mechanism to accomplish such a program is not clear at this time. At present, no emission reductions are credited for reduction of the ongoing leaks associated with current DIY practice. The delayed emissions under the industry remain equal to the 0.47 MMTCO_2E per year emitted under BAU.

Total annual emissions associated with the industry proposal with a 75% can return rate are thus 0.52 MMTCO_2E. And annual emission reductions are 0.19 MMTCO_2E per year (Figure 4).

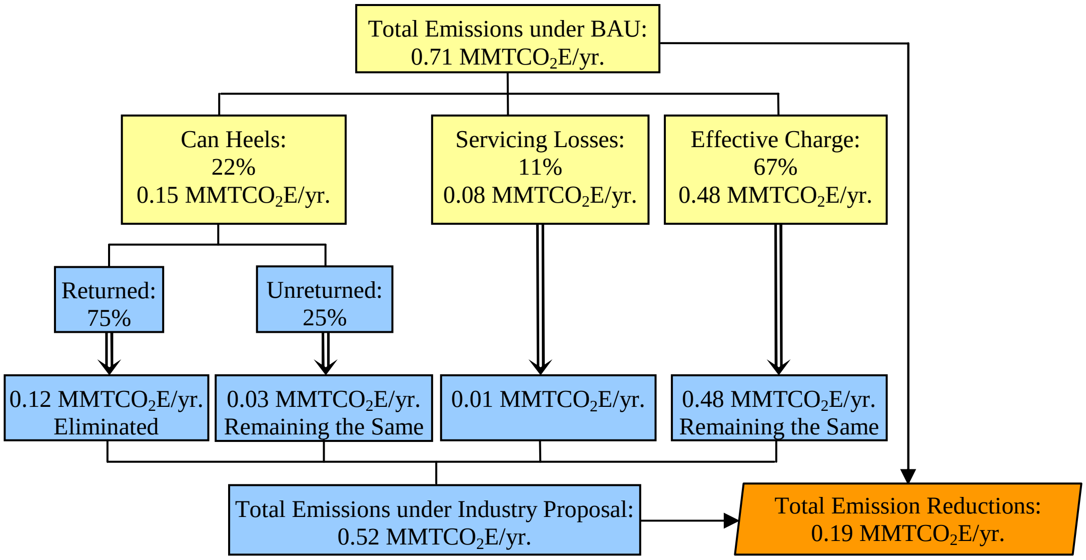

Figure 4. HFC-134a Emissions under Industry Proposal

<u>Costs</u>

The cost of fitting a valve to each can is estimated by industry to be $0.25 per can. The cost of operating the recycling program is estimated by industry to be about $0.75 per can. These costs, totaling $1 per can, would be passed on to the consumer in the increased price of the can. At 1.6 million cans per year the increased consumer cost is $1.6 million.

The deposit amount, currently proposed at $5 per can, would in theory be returned to the consumer. However, the can return rate is unlikely to be 100%. The unclaimed deposits could go into an escrow account used for GHG emission mitigation efforts, offset the retailer's cost of handling the returns, fund public can return education programs, etc. However, for purpose of this analysis the unclaimed deposits are simply counted as additional cost to the consumer. Given a 75% can return rate and a $5 deposit per can, the 25% of unclaimed deposits come to $2 million per year.

Total increased cost to the consumer is thus $3.6 million per year.

<u>Cost-Effectiveness</u>

Cost-effectiveness under this proposal is calculated here using only the increased costs to consumers.

The emissions reduction under the industry proposal with 75% return rate is 0.19 MMTCO$_2$E. The increased consumer cost is $3.6 million for increased can costs plus unclaimed deposits. The cost of emission reduction borne by the consumer is then about $19/MTCO$_2$E.

Enhanced Industry Proposal

Practice

ARB staff propose enhancements to the industry proposal to further reduce emissions and ensure higher confidence in realizing the emission reductions brought about by the industry proposal. This approach will include, in addition to the industry proposal, a mandatory return rate target of probably 95%, and a comprehensive DIY education program. At periodic intervals the return rate would be assessed by ARB. If the return rate target is not met, then the deposit will be significantly increased. This process would continue until the target recycle rate is achieved. The education program would cover the deposit program, environmental issues (ozone depletion and global warming) that are associated with refrigerant emissions, fundamentals of MVAC systems, recommended procedures for DIY recharging, and potential risks of improper recharging.

Improved usage instructions on the small cans and DIY education program will better inform consumers of the potential risk to their AC and damage to the climate system from DIY recharging, thus discourage some of them continuing DIY recharging. However, this cannot be quantified at this point. In this analysis, it is assumed that no consumer would change DIY behavior due to this regulation.

Emissions

It is anticipated that with improved can instructions and DIY education program, the servicing losses would likely be reduced to minimal. Thus, the 0.08 $MMTCO_2E$ of emissions due to servicing are eliminated.

The emissions due to can heels were 0.15 $MMTCO_2E$ per year under BAU. With the self-sealing valve, the heel will be contained in the can. If the target return rate of 95% is met, these emissions will be reduced to 0.008 $MMTCO_2E$. So the emission reductions will be about 0.14 MMTCO2E.

We expect that the consumer education program would increase the number of DIY users motivated to find and repair leaks. However, we have not quantified this change in consumer behavior and for the purpose of analysis the delayed emissions of 0.48 $MMTCO_2E$ per year are assumed to remain the same.

Therefore, the enhanced industry proposal would achieve 0.22 $MMTCO_2E$ per year in emission reductions and the annual emissions would be 0.49 $MMTCO_2E$ (Figure 5),

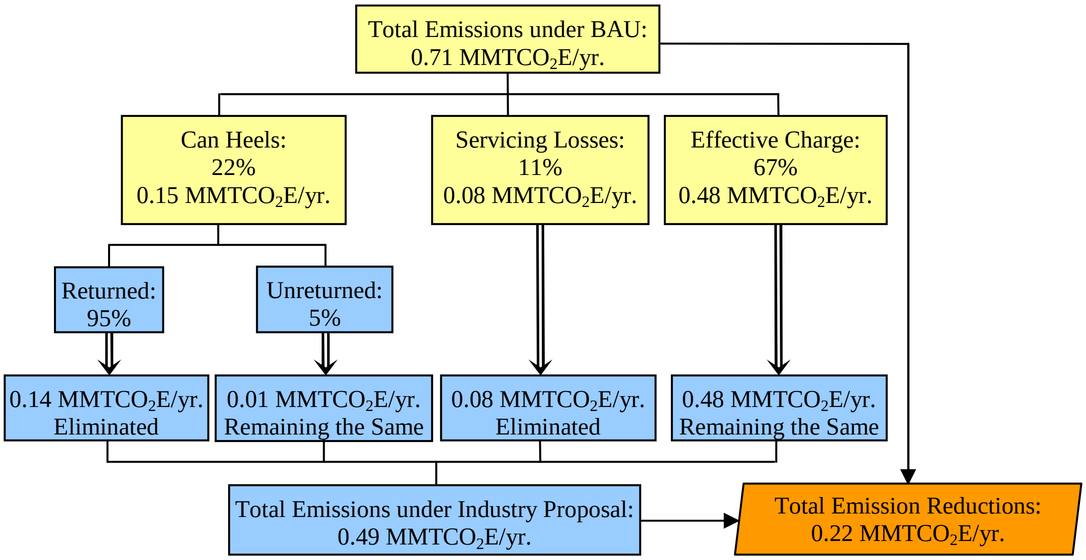

Figure 5. HFC-134a Emissions under Enhanced Industry Proposal

Costs

Similar to the industry proposal, the extra cost of $1 per can due to the self-sealing valve and recycling program would be passed on to the consumer in the increased price of the can. At 1.6 million cans per year the increased consumer cost is $1.6 million.

Given a 95% can return rate and a $5 deposit per can, the 5% of unclaimed deposits come to $0.4 million per year and will be an additional cost to the consumers.

Total increased cost to the consumer is thus $2 million per year.

Cost-Effectiveness

Under this enhanced industry proposal, about 0.22 $MMTCO_2E$ of emissions would be reduced per year at an increased cost of $2 million per year. The cost-effectiveness is then about $9/$MTCO_2E$.

Fee-Based Alternative

Practice

A fourth approach to reducing emissions from small cans would be to charge a fee per can, or a fee per mass of HFC-134a. The following discussion is presented on a per can basis. DIY practice would be as described under BAU, except that consumers would pay an additional fee per can at the time of purchase. The fee approach could also be combined with the Industry, or the Enhanced Industry proposal.

Emissions

A typical small can contains about 12 ounces weight or 340 grams of HFC-134a. The GWP of HFC-134a is 1300, so the typical small can contains about 0.44 $MTCO_2E$. An approximation useful for mental arithmetic is that each can of HFC-134a contains about one half metric ton of CO_2 equivalent.

A carbon fee attached to the HFC-134a in small cans could affect greenhouse gas emissions in two ways. First, depending on the size of the fee, the fee might cause reduction in consumer use of small cans. Second, the fee could be used by the State to "neutralize" the emissions via State sanctioned projects—most probably in-State projects verified using State approved protocols.

Note that the fee approach could be easily combined with the portion of the industry proposal that adds valves and improved instructions to the small cans, or with the entire industry proposal including recycling. It is important to remember that ARB still desires to generate within-sector reductions to the extent feasible. The fee-based approach is compatible with parallel emission reduction efforts. Fees are especially helpful in achieving net reductions in the short-term. The short-term reductions can be the initial phase of a longer term backstop strategy such as the eventual phase out of high-GWP refrigerants and replacement with low-GWP refrigerants.

The disincentive effects of the fee on emissions and costs can be analyzed using the same model as for the small can ban with a minor addition. In the ban model, former DIY users are apportioned into four categories: obtain professional repairs, obtain professional top off, forgo air conditioning, or obtain and use HFC-134a by alternate means. In the fee model, one more category is needed: continue to use legal DIY small cans. This last category has the same emission impact as "obtain and use HFC-134a by alternate means" (i.e., no reduction from BAU), but the cost implications are different. We have not presented quantitative results from this model because we do not have the data needed to predict reduction in small can use on the basis of fee magnitude.

Fees set commensurate with the cost of carbon are not likely to cause much actual emission reduction within the sector because at current carbon trading prices (ETS CERs, March 2008), the fees would be small compared to the cost of professional servicing. Even though in-sector emissions of CO_2E would not be significantly reduced, using the fees for carbon mitigation would reduce Statewide net emissions of CO_2E. If the fee per can were set to offset the contents per can, then the net statewide emissions would be reduced by the total sale of CO_2E in small cans, which is 0.85 $MMTCO_2E$/year. In this fee scenario, small can sales to non-DIY professionals are included in the benefit. In the ban scenario, small can sales to professionals were excluded because there is likely to be little emission savings in switching from small can use by professionals to large can use by professionals. But the mitigation benefits of the fee are realized no matter who purchases the can.

Small can use is not necessarily the only activity for which a mitigation fee may be a viable option. For example, it might be more appropriate to require a mitigation fee for all use of HFC-134a (or even other high-GWP substances), regardless of container size. The fee could even extend to factory installed HFC-134a in new vehicles. We are currently in the process of identifying legal, technical, and practical constraints with the inclusion of a mitigation fee.

<u>Costs</u>

We do not have data to support a quantitative relationship between fee value and reduction in small can use. However, many DIYers use small cans to avoid the cost of professional work. A professional top-off costs about \$100 and professional mobile air conditioning repairs cost, on average, about \$650. A fee would probably not have substantial impact on small can use unless it represented a substantial fraction of the cost of professional work.

The intention of this discussion is not to specify a market or set a fee but to give an example. The actual fee mechanisms would need to be developed as part of a larger State program. The State needs flexibility to achieve its Scoping Plan targets, and industry needs a certain stability in fee structure to operate business successfully. For the purpose of example, if the fee were set at \$25/$MTCO_2E$, then the fee for a typical can would be about \$11/can.

<u>Cost-Effectiveness</u>

If the fees were set high enough to cause significant reduction in can use, then former DIYers would be driven to a mix of options similar to those chosen in the case of the ban. The cost-per-ton would be similar to that of the ban plus the addition of the can fee, thus making it less cost-effective than the ban. The cost-effectiveness of a fee used to mitigate emissions would be expected to be determined using a metric that links to the costs of getting equivalent, and robust reductions. For example, assuming a mitigation fee of \$25/$MTCO_2E$ translates into a cost-effectiveness of \$25/$MTCO_2E$.

SUMMARY

The can ban approach would eliminate approximately 0.47 $MMTCO_2E$ per year of HFC-134a emissions from DIY recharging of MVAC using small cans at a cost of about \$135/$MTCO_2E$ to the consumer plus \$25 million per year in lost revenues to industry. About 0.13 $MMTCO_2E$ of the reduction depends on the ability of professionals to service systems with 10% service loss and 2% can heel. About 0.21 $MMTCO_2E$ of the reduction depends on 49% of the former DIYers obtaining professional repairs, and the ability of professional repairs to reduce average leak rates by a factor of six. Another 0.14 $MMTCO_2E$ per year depends on 21% of consumers choosing to forgo air conditioning in their vehicle.

The industry alternative proposal to improve equipment, improve instructions, and establish a recycle program with 75% can return rate would eliminate about 0.19 $MMTCO_2E$ per year at a cost to the consumer of about \$19/$MTCO_2E$. About 0.07 $MMTCO_2E$ per year of the reduction depends on 90% of consumers following servicing instructions carefully. About 0.12 $MMTCO_2E$ per year of the estimated reduction depends on 75% of consumers choosing to recycle cans, and on the ability of the packager or recycling contractor to recover 100% of can heels from recycled cans.

The enhanced industry proposal adds to the industry proposal a mandatory return and recycling program for the can, a target can return rate of 95%, and a comprehensive DIY education program. It could achieve emission reductions of 0.22 $MMTCO_2E$ per year even if no DIYers change their behavior. The increased cost is \$2 million per year and the cost-effectiveness works out to be \$9/$MTCO_2E$.

A mitigation fee could be used by the State to mitigate emissions equal to the small can sales, which are currently 0.85 $MMTCO_2E$/year. As an example it follows that a mitigation fee of \$25/$MTCO_2E$, for example, would translate into a cost-effectiveness of \$25/$MTCO_2E$. The fee-based approach, with fees to support emission mitigation roughly equivalent to the can contents, would probably not cause a substantial reduction of actual emissions within the sector (i.e., the number of DIY cans used). The fee-based approach needs to be considered in conjunction with other emission reduction approaches to achieve long-term gains.

Table 1: Emissions and Economic Impacts under BAU and Regulatory Proposals

Scenario	Emissions $MMTCO_2E$/yr.	Emission Reductions $MMTCO_2E$/yr.	Cost-Effectiveness (Consumer Side) Dollars/$MTCO_2E$	Lost Revenue Million Dollars/yr.
BAU	0.71	NA	NA	NA
Can Ban	0.24	0.47	135	25
Industry Proposal*	0.52	0.19	19	0
Enhanced Industry Proposal**	0.49	0.22	9	<1
Fee-for-Mitigation	0.85	0.85	25***	0

* Assume 75% of can return rate.
** Enhanced Industry Proposal sets a mandatory can return target of 95%.
*** Depends on carbon market price.

APPENDIX A
DETAILS OF ASSUMPTIONS AND CALCULATIONS FOR THE EMISSIONS AND ECONOMIC IMPACTS ANALYSIS

Table A.1: Emissions and Economic Impacts under BAU and Three Proposals

	BAU	Can Ban	Industry Proposal	Enhanced Industry Proposal
Annual Can Sales to DIYers (million cans)	1.6	NA	1.6	1.6
Annual Emissions ($MMTCO_2E$)	0.71	0.24	0.51	0.49
Annual Emission Reductions ($MMTCO_2E$)	NA	0.47	0.19	0.22
Annual Revenue Loss (million dollars)	NA	25	0	0
Annual Extra Costs for All Leaky Vehicles (million dollars)	NA	62.9	3.6	2
Cost-effectiveness to Consumers (dollars/$MTCO_2E$)	NA	135	19	9
Lifetime Costs for a Leaky Vehicle (dollars)	152	613	178	167

Table A.2: Independent Parameters

Notation	Definition	Estimate	References
E_{can}	Amount of HFC-134a sold in small cans annually in CA	0.85 $MMTCO_2E$	ARB, 2007b
S_{can}	Number of small cans sold annually in CA	2 million	Same as the above
Y	Vehicle's average lifetime	16 years	Vincent et al., 2004
Y_0	Average time after which a leaky vehicle's AC needs its first recharge	7 years	I-MAC Team, 2007
Y_1	Average time that a leaky MVAC recharged without repair lasts before it needs another recharge	1 year	ARB staff estimate based on various data sources
Y_2	Average time that a leaky MVAC repaired and recharged by a professional shop lasts before it needs another repair and recharge	6 years	Thundiyil, 2007
N_C	Average number of small cans needed for a DIY recharging event	1.3 cans	Clodic, 2007
P_0	Percentage of HFC-134a in small cans sold to DIYers in CA	83%	ARB staff estimate based on three data sources: ARPI, 2008; Atkinson, 2008a; and MACS, 2008
P_{11}	Average percentage of can heels during DIY recharging	22%	Clodic et al., 2007
P_{12}	Average percentage of servicing leaks during DIY recharging	11%	Same as the above
P_{21}	Percentage of original DIYers (under BAU) that would pay for professional diagnosis, repair and recharge should a 'Can Ban' regulation be implemented	49%	ARB staff estimate based on two data sources: Frost & Sullivan, 2006; and Atkinson, 2008b
P_{22}	Percentage of original DIYers (under BAU) that would not pay professional repair and hence would not have their MVACs recharged any more should a 'Can Ban' regulation be implemented	21%	Same as the above

P_{23}	Percentage of original DIYers (under BAU) that would choose to top off at professional shops should a 'Can Ban' regulation be implemented	10%	Same as the above
P_{24}	Average percentage of can heels during professional recharge	2%	ARB staff estimate based on assumptions in the GREEN-MAC-LCCP Model (Papasavva et al., 2008)
P_{25}	Average percentage of servicing leaks during professional recharge	10%	Same as the above
P_{31}	Percentage of DIYers that return the used cans (under industry proposal)	75%	ARB staff estimate based on ARPI's pilot study
P_{32}	Average percentage of servicing leaks during DIY recharging under industry proposal	1%	ARB staff estimate based on two data sources: Frost & Sullivan, 2006; and Clodic, 2007
P_{41}	Percentage of DIYers that return the used cans (under hybrid approach)	95%	Targeted return rate in the mandatory recycling program of hybrid approach
P_{42}	Percentage of DIYers that would change behavior under hybrid approach	0%	Most conservative scenario
P_5	Percentage of increase in DIY cost for people seeking alternative ways to obtain small cans should a 'Can Ban' regulation be implemented	50%	ARB staff estimate
R_1	Average retail price for a small can	$13	NPD, 2008
R_{21}	Price increment for a small can under industry proposal	$1	ARPI, 2008a
R_{22}	Redemption value for a small can under industry proposal	$5	Assumed value to ensure relatively high return rate
R_{edu}	Annual extra cost per consumer due to the addition of the voluntary DIY education program	$0	Most conservative estimate
R_{31}	Average price for a professional diagnosis, repair and recharge of a leaky MVAC	$650	ARB staff estimate based on MACS 2003 Survey (MACS, 2008)
R_{32}	Average price for a professional recharge of a leaky MVAC	$100	Clodic, 2008

Assumptions

1. The percentage of charge that a 'leaky' MVAC has to lose before a recharge takes place is the same under DIY operation and professional repair and recharge. As a side note, the USEPA Vintaging Model assumes that an AC system requires servicing when the refrigerant level drops below 50%.

2. The refrigerant recovered in professional servicing will be properly recycled or reclaimed and cause no emissions.

3. Under the industry proposal, servicing leaks can be reduced by providing better instructions to the DIYers and having self-sealing valves to the can. Emissions due to can heels for the portion of the DIYers who return the used cans are negligible due to self-sealing valves.

4. Under the industry proposal, a DIYer would either return the used can and get the refund or dispose of the can and the refrigerant content inside the can would eventually be emitted to the atmosphere.

Notes

1. This analysis does not take into account the change in vehicle population.

2. The estimation in this analysis is decoupled from the climate benefits from other Early Action measures including "Addition of AC leak test and repair requirement to smog check", "Requirement of low-GWP refrigerants for new MVAC", and "Reductions of HFC-134a emissions from professional servicing of MVAC".

Analysis

1. BAU

Number of small cans sold to DIYers annually in CA is

$$S_{\text{sale}} = P_0 \cdot S_{\text{can}}$$
$$= 83\% \times 2 = 1.66 \text{ (million cans)}$$

This leads to the annual emissions of

$$E = P_0 \cdot E_{\text{can}}$$
$$= 83\% \times 0.85 = 0.706 \text{ (MMTCO}_2\text{E)}$$

Nominal number of small cans sold to DIYers annually in CA (assuming 12 oz / can):

$$S = \frac{E}{12\text{oz} \cdot 0.02835 \dfrac{\text{kg}}{\text{oz}} \cdot 10^{-9} \dfrac{\text{MMT}}{\text{kg}} \cdot 1300 \dfrac{\text{MMTCO}_2\text{E}}{\text{MMT}}} = 2.261 \times 10^6 \cdot E \quad ,$$
$$= 2.261 \times 10^6 \times 0.706 = 1.596 \text{ (million cans)}$$

which is close to the actual number of small cans sold to DIYers annually in CA (1.66 million). This is mainly because the majority of the market share of small cans is in 12 oz, and 12 oz is a fair estimate of the average can size. Thus, the following calculation will not differentiate S_{sale} and S and will use S whenever the number of cans is needed.

Number of unique DIY vehicles:

$$N_V = \frac{Y_1 \cdot S}{N_C}$$
$$= \frac{1 \times 1.596}{1.3} = 1.227 \text{ (million vehicles)}$$

Note that a vehicle that gets multiple recharges during its lifetime is counted as one unique DIY vehicle.

Adjusted lifetime for recharging (referred to hereafter as 'lifetime'):

$$Y_{\text{adj}} = Y - Y_0$$
$$= 16 - 7 = 9 \text{ (years)} ,$$

which is the lifespan of interest to us during which repair / recharge happens.

Number of recharges in a leaky vehicle's lifetime:

$$N_{\text{R,BAU}} = \frac{Y_{\text{adj}}}{Y_1}$$
$$= \frac{9}{1} = 9 \text{ (times)}$$

Lifetime costs for a DIY vehicle:

$$C_{\text{L,BAU}} = N_{\text{R,BAU}} \cdot N_{\text{C}} \cdot R_1$$
$$= 9 \times 1.3 \times 13 = 152.10 \text{ (dollars)}$$

Annual costs for a DIY vehicle:

$$C_{\text{BAU}} = \frac{C_{\text{L,BAU}}}{Y_{\text{adj}}} = \frac{N_{\text{R,BAU}} \cdot N_{\text{C}} \cdot R_1}{Y_{\text{adj}}} = \frac{N_{\text{C}} \cdot R_1}{Y_1}$$
$$= \frac{152.10}{9} = 16.90 \text{ (dollars)}$$

Annual costs for all DIY vehicles:

$$C_{\text{all,BAU}} = S \cdot R_1$$
$$= 1.595 \times 13 = 20.74 \text{ (million dollars)}$$

2. 'Can Ban'

Under BAU, the N_V 'leaky' vehicles that have been DIY recharged would leak on average M_{BAU} (in $MMTCO_2E$) of refrigerant per vehicle during Y_1 years. This total amount of 'system leaks' should be equal to total emissions due to system leaks over Y_1 years:

$$Y_1 \cdot E = \frac{N_{\text{V}} \cdot M_{\text{BAU}}}{1 - P_{11} - P_{12}}.$$

Under the 'Can Ban' regulation, a fraction (P_{21}) of the same leaky vehicles would be taken to professional shops for diagnosis, repair and recharge. They would then leak slowly until they lose on average M_{ban} of refrigerant per vehicle during Y_2 years. Another fraction (P_{22}) of the leaky vehicles would not get repair and recharge and hence would eventually go without A/C, generating no refrigerant leaks. The rest of the leaky vehicles would be taken to professional shops only for recharge. The amount recharged to their A/C systems would leak over Y_1 years, similar to the systems that would have been DIY recharged. The total amount of system leaks should be equal to the fraction of total emissions (assumed to be E_{ban} per year) that is due to system leaks over Y_2 years:

$$Y_2 \cdot E_{\text{ban}} = \frac{P_{21} \cdot N_{\text{V}} \cdot M_{\text{ban}} + \frac{Y_2}{Y_1} \cdot P_{23} \cdot N_{\text{V}} \cdot M_{\text{ban}}}{1 - P_{24} - P_{25}} + \frac{\frac{Y_2}{Y_1} \cdot (1 - P_{21} - P_{22} - P_{23}) \cdot N_{\text{V}} \cdot M_{\text{ban}}}{1 - P_{11} - P_{12}}.$$

Based on Assumption 1,

$$M_{\text{ban}} = M_{\text{BAU}}.$$

Thus,

$$E_{\text{ban}} = [\frac{1-P_{11}-P_{12}}{1-P_{24}-P_{25}} \cdot (\frac{Y_1}{Y_2} \cdot P_{21} + P_{23}) + (1-P_{21}-P_{22}-P_{23})] \cdot E$$
$$= [\frac{1-22\%-11\%}{1-10\%-2\%} \times (\frac{1}{6} \times 49\% + 10\%) + (1-49\%-21\%-10\%)] \times 0.706 = 0.239 \text{ (MMTCO}_2\text{E)}$$

Note that under ‘Can Ban’, the above calculated annual emissions will be less than the refrigerant sales attributed to this portion of usage. This is because the technician would first vacate the A/C and then charge the nominal amount of refrigerant and according to Assumption 2, the recovered portion of the refrigerant will be properly treated and will not cause emissions.

Annual emission reductions:

$$ER_{\text{ban}} = E - E_{\text{ban}} = E - [\frac{1-P_{11}-P_{12}}{1-P_{24}-P_{25}} \cdot (\frac{Y_1}{Y_2} \cdot P_{21} + P_{23}) + (1-P_{21}-P_{22}-P_{23})] \cdot E$$
$$= [(P_{21}+P_{22}+P_{23}) - \frac{1-P_{11}-P_{12}}{1-P_{24}-P_{25}} \cdot (\frac{Y_1}{Y_2} \cdot P_{21} + P_{23})] \cdot E$$
$$= 0.706 - 0.239 = 0.467 \text{ (MMTCO}_2\text{E)}$$

Number of professional repairs and recharges in a leaky vehicle’s lifetime:

$$N_{\text{R,ban}} = \frac{Y_{\text{adj}}}{Y_2}$$
$$= \frac{9}{6} = 1.5 \text{ (times)}$$

Lifetime costs for a leaky vehicle that would have been DIY vehicle but whose owner chooses to have professional repair and recharge when ‘Can Ban’ is in place:

$$C_{\text{1,L,ban}} = N_{\text{R,ban}} \cdot R_{31} = \frac{Y_{\text{adj}}}{Y_2} \cdot R_{31}$$
$$= 1.5 \times 650 = 975 \text{ (dollars)}$$

The number of professional recharges in a leaky vehicle’s lifetime would be the same as under BAU ($N_{\text{R,BAU}}$) if its owner choose topping off without leaking problems fixed. Lifetime costs for such a leaky vehicle are:

$$C_{\text{2,L,ban}} = N_{\text{R,BAU}} \cdot R_{32} = \frac{Y_{\text{adj}}}{Y_1} \cdot R_{32}$$
$$= 9 \times 100 = 900 \text{ (dollars)}$$

Number of recharges in a leaky vehicle’s lifetime would be the same as under BAU ($N_{\text{R,BAU}}$) if its owner obtains refrigerant through alternative ways. Lifetime costs for such a leaky vehicle are:

$$C_{\text{3,L,ban}} = (1+P_5) \cdot C_{\text{L,BAU}} = (1+P_5) \cdot N_{\text{R,BAU}} \cdot N_{\text{C}} \cdot R_1 = \frac{Y_{\text{adj}}}{Y_1} \cdot N_{\text{C}} \cdot (1+P_5) \cdot R_1$$
$$= (1+50\%) \times 152.10 = 228.15 \text{ (dollars)}$$

Note that the owners for the rest of the leaky vehicles that would be DIY vehicles would choose to forgo A/C and thus incur no costs.

Annual costs for all leaky vehicles that would have been DIY vehicles:

$$C_{\text{all,ban}} = \frac{P_{21} N_{\text{V}} C_{1,\text{L,ban}} + P_{23} N_{\text{V}} C_{2,\text{L,ban}} + (1 - P_{21} - P_{22} - P_{23}) N_{\text{V}} C_{3,\text{L,ban}}}{Y_{\text{adj}}}$$

$$= \frac{S}{N_{\text{C}}} \cdot [\frac{Y_1}{Y_2} \cdot P_{21} \cdot R_{31} + P_{23} \cdot R_{32} + (1 - P_{21} - P_{22} - P_{23}) \cdot (1 + P_5) \cdot R_1]$$

$$= \frac{49\% \times 1.227 \times 975 + 10\% \times 1.227 \times 900 + (1 - 49\% - 21\% - 10\%) \times 1.227 \times 228.15}{9} = 83.63 \text{ (million dollars)}$$

Average lifetime costs for a DIY vehicle are:

$$C_{\text{L,ban}} = \frac{Y_{\text{adj}} \cdot C_{\text{all,ban}}}{N_{\text{V}}}$$

$$= \frac{9 \times 83.63}{1.227} = 613.38 \text{ (dollars)}$$

Annual extra costs for all leaky vehicles that would have been DIY vehicles:

$$EC_{\text{all,ban}} = C_{\text{all,ban}} - C_{\text{all,BAU}} = \frac{S}{N_{\text{C}}} \cdot [\frac{Y_1}{Y_2} \cdot P_{21} \cdot R_{31} + P_{23} \cdot R_{32} + (1 - P_{21} - P_{22} - P_{23}) \cdot (1 + P_5) \cdot R_1] - S \cdot R_1$$

$$= S \cdot [\frac{\frac{Y_1}{Y_2} \cdot P_{21} \cdot R_{31} + P_{23} \cdot R_{32} + (1 - P_{21} - P_{22} - P_{23}) \cdot (1 + P_5) \cdot R_1}{N_C} - R_1]$$

$$= 83.63 - 20.74 = 62.89 \text{ (million dollars)}$$

Cost-effectiveness to consumers:

$$CE_{\text{cons,ban}} = \frac{EC_{\text{all,ban}}}{ER_{\text{ban}}} = \frac{S \cdot [\frac{\frac{Y_1}{Y_2} \cdot P_{21} \cdot R_{31} + P_{23} \cdot R_{32} + (1 - P_{21} - P_{22} - P_{23}) \cdot (1 + P_5) \cdot R_1}{N_C} - R_1]}{[(P_{21} + P_{22} + P_{23}) - \frac{1 - P_{11} - P_{12}}{1 - P_{24} - P_{25}} \cdot (\frac{Y_1}{Y_2} \cdot P_{21} + P_{23})] \cdot E}$$

$$= \frac{S}{E} \cdot \frac{\frac{\frac{Y_1}{Y_2} \cdot P_{21} \cdot R_{31} + P_{23} \cdot R_{32} + (1 - P_{21} - P_{22} - P_{23}) \cdot (1 + P_5) \cdot R_1}{N_C} - R_1}{(P_{21} + P_{22} + P_{23}) - \frac{1 - P_{11} - P_{12}}{1 - P_{24} - P_{25}} \cdot (\frac{Y_1}{Y_2} \cdot P_{21} + P_{23})}$$

$$= \frac{62.89}{0.467} = 134.72 \text{ (dollars/MTCO}_2\text{E)}$$

Annual revenue loss by small can industry:

$$RL_{\text{ban}} = \frac{S}{P_0} \cdot R_1$$

$$= \frac{1.595}{83\%} \times 13 = 24.98 \text{ (million dollars)}$$

Note that 17% of the small cans (1 - P_0) are sold to professional shops. If 'Can Ban' regulation was implemented, the small can industry would also lose this fraction of the market. Also note that for the DIYers who would choose to obtain small cans through alternative ways may purchase cans from internet or out-of-state, which may to some extent offset the revenue lost within California but not all since cans could be produced out-of-country from different group of industry. No data are available to break down the leakage.

3. Industry Proposal

Under Industry Proposal, to the number of DIY vehicles would be the same as under BAU. A fraction of the users (P_{31}) would return the cans, hence only incur servicing leaks and delayed emissions (Assumption 3), which is equivalent to the effective charge. The rest of the users would incur delayed emissions (Assumption 3), servicing leaks, and emissions due to can heels (Assumption 4). Note that the servicing leaks would be less than that under BAU due to the improved instructions and self-sealing valve. Thus the annual emissions would be:

$$Y_1 \cdot E_{\text{ind}} = \frac{P_{31} \cdot N_{\text{V}} \cdot M_{\text{ind}} \cdot (1-P_{11})}{1-P_{11}-P_{32}} + \frac{(1-P_{31}) \cdot N_{\text{V}} \cdot M_{\text{ind}}}{1-P_{11}-P_{32}}$$

Based on Assumption 1,

$$M_{\text{ind}} = M_{\text{BAU}} .$$

Thus,

$$E_{\text{ind}} = \frac{(1-P_{31} \cdot P_{11}) \cdot (1-P_{11}-P_{12})}{1-P_{11}-P_{32}} \cdot E$$

$$= \frac{(1-75\% \times 22\%) \times (1-22\%-11\%)}{1-22\%-1\%} \times 0.706 = 0.513 \text{ (MMTCO}_2\text{E)}$$

Annual emission reductions:

$$ER_{\text{ind}} = E - E_{\text{ind}} = E - \frac{(1-P_{31} \cdot P_{11}) \cdot (1-P_{11}-P_{12})}{1-P_{11}-P_{32}} \cdot E = [1 - \frac{(1-P_{31} \cdot P_{11}) \cdot (1-P_{11}-P_{12})}{1-P_{11}-P_{32}}] \cdot E$$

$$= 0.706 - 0.513 = 0.193 \text{ (MMTCO}_2\text{E)}$$

Annual costs for all DIY vehicles:

$$C_{\text{all,ind}} = S \cdot [P_{31} \cdot (R_1 + R_{21}) + (1-P_{31}) \cdot (R_1 + R_{21} + R_{22})] = S \cdot [R_1 + R_{21} + (1-P_{31}) \cdot R_{22}]$$

$$= 1.595 \times [13 + 1 + (1-75\%) \times 5] = 24.33 \text{ (million dollars)}$$

Annual extra costs for all DIY vehicles:

$$EC_{\text{all,ind}} = C_{\text{all,ind}} - C_{\text{all,BAU}} = S \cdot [R_1 + R_{21} + (1-P_{31}) \cdot R_{22}] - S \cdot R_1 = S \cdot [R_{21} + (1-P_{31}) \cdot R_{22}]$$

$$= 24.33 - 20.74 = 3.59 \text{ (million dollars)}$$

Cost-effectiveness to consumers:

$$CE_{\text{cons,ind}} = \frac{EC_{\text{all,ind}}}{ER_{\text{ind}}} = \frac{S \cdot [R_{21} + (1-P_{31}) \cdot R_{22}]}{[1 - \frac{(1-P_{31} \cdot P_{11}) \cdot (1-P_{11}-P_{12})}{1-P_{11}-P_{32}}] \cdot E} = \frac{S}{E} \cdot \frac{R_{21} + (1-P_{31}) \cdot R_{22}}{1 - \frac{(1-P_{31} \cdot P_{11}) \cdot (1-P_{11}-P_{12})}{1-P_{11}-P_{32}}}$$

$$= \frac{3.59}{0.193} = 18.60 \text{ (dollars/MTCO}_2\text{E)}$$

Lifetime costs for a DIY vehicle:

$$C_{\text{L,ind}} = \frac{Y_{\text{adj}} \cdot C_{\text{all,ind}}}{N_{\text{V}}} = \frac{Y_{\text{adj}}}{Y_1} \cdot N_{\text{C}} \cdot [R_1 + R_{21} + (1-P_{31}) \cdot R_{22}]$$

$$= \frac{9 \times 24.33}{1.227} = 178.43 \text{ (dollars)}$$

Annual revenue loss by small can industry:

$$RL_{\text{ind}} = 0$$

4. Enhanced Industry Proposal

The comprehensive DIY education program and improved instructions on the can might discourage some DIYers to perform the DIY recharging due to increased knowledge of the potential risk to the AC and damage to the climate. However, this cannot be quatified at this time. For the purpose of this analysis, we assume no DIY will switch to professional servicing due to the measure. Additionally, the education program and improved instructions could further reduce the servicing leaks, likely down to mininal. They, together with the mandatory recycling program and deposit increase mechanism, would improve the can return rate to the targeted 95%. The annual emissions would be:

$$Y_2 \cdot E_{\text{enh}} = (1-P_{42}) \cdot [\frac{\frac{Y_2}{Y_1} \cdot P_{41} \cdot N_{\text{V}} \cdot M_{\text{enh}} \cdot (1-P_{11})}{1-P_{11}-P_{32}} + \frac{\frac{Y_2}{Y_1} \cdot (1-P_{41}) \cdot N_{\text{V}} \cdot M_{\text{enh}}}{1-P_{11}-P_{32}}]$$

$$+ P_{42} \cdot [\frac{P_{21} \cdot N_{\text{V}} \cdot M_{\text{enh}} + \frac{Y_2}{Y_1} \cdot P_{23} \cdot N_{\text{V}} \cdot M_{\text{enh}}}{1-P_{24}-P_{25}} + \frac{\frac{Y_2}{Y_1} \cdot (1-P_{21}-P_{22}-P_{23}) \cdot N_{\text{V}} \cdot M_{\text{enh}}}{1-P_{11}-P_{12}}]$$

Based on Assumption 1,

$$M_{\text{enh}} = M_{\text{BAU}} .$$

Thus,

$$E_{\text{enh}} = [\frac{(1-P_{42})\cdot(1-P_{41}\cdot P_{11})\cdot(1-P_{11}-P_{12})}{1-P_{11}-P_{32}} + \frac{P_{42}\cdot(\frac{Y_1}{Y_2}P_{21}+P_{23})\cdot(1-P_{11}-P_{12})}{1-P_{24}-P_{25}}$$
$$+P_{42}\cdot(1-P_{21}-P_{22}-P_{23})]\cdot E$$
$$=[\frac{(1-0\%)\times(1-95\%\times 22\%)\times(1-22\%-11\%)}{1-22\%-1\%} + \frac{0\%\times(\frac{1}{6}\times 49\%+10\%)\times(1-22\%-11\%)}{1-2\%-10\%}$$
$$+0\%\times(1-49\%-21\%-10\%)]\times 0.706$$
$$=0.486\ (\text{MMTCO}_2\text{E})$$

Note that the above calculation assumes that no one would change their DIY behavior.

Annual emission reductions:

$$ER_{\text{enh}} = E - E_{\text{enh}}$$
$$=[1-\frac{(1-P_{42})\cdot(1-P_{41}\cdot P_{11})\cdot(1-P_{11}-P_{12})}{1-P_{11}-P_{32}} - \frac{P_{42}\cdot(\frac{Y_1}{Y_2}P_{21}+P_{23})\cdot(1-P_{11}-P_{12})}{1-P_{24}-P_{25}}$$
$$-P_{42}\cdot(1-P_{21}-P_{22}-P_{23})]\cdot E$$
$$=0.706-0.486=0.220\ (\text{MMTCO}_2\text{E})$$

Establishing the comprehensive DIY education program will need financial and human resources. At this point, it is not clear whether the additional cost would be passed onto consumers. For the purpose of this analysis, it is assumed that no additional cost would incur by this education program. Then the annual costs for all DIY vehicles are:

$$C_{\text{all,enh}} = (1-P_{42})\cdot\{S\cdot[P_{41}\cdot(R_1+R_{21})+(1-P_{41})\cdot(R_1+R_{21}+R_{22})]+N_{\text{V}}\cdot R_{\text{edu}}\}$$
$$+P_{42}\cdot\frac{S}{N_{\text{C}}}\cdot[\frac{Y_1}{Y_2}\cdot P_{21}\cdot R_{31}+P_{23}\cdot R_{32}+(1-P_{21}-P_{22}-P_{23})\cdot(1+P_5)\cdot R_1]$$
$$=(1-P_{42})\cdot S\cdot[R_1+R_{21}+(1-P_{41})\cdot R_{22}+\frac{Y_1}{N_{\text{C}}}R_{\text{edu}}]$$
$$+P_{42}\cdot\frac{S}{N_{\text{C}}}\cdot[\frac{Y_1}{Y_2}\cdot P_{21}\cdot R_{31}+P_{23}\cdot R_{32}+(1-P_{21}-P_{22}-P_{23})\cdot(1+P_5)\cdot R_1]$$
$$=(1-0\%)\times 1.595\times[13+1+(1-95\%)\times 5)+\frac{1}{1.3}\times 0]$$
$$+0\%\times\frac{1.595}{1.3}\times[\frac{1}{6}\times 49\%\times 650+10\%\times 100+(1-49\%-21\%-10\%)\times(1+50\%)\times 13]$$
$$=22.73\ (\text{million dollars})$$

Annual extra costs for all DIY vehicles:

$$EC_{\text{all,enh}} = C_{\text{all,enh}} - C_{\text{all,BAU}}$$
$$=(1-P_{42})\cdot S\cdot[R_1+R_{21}+(1-P_{41})\cdot R_{22}+\frac{Y_1}{N_{\text{C}}}R_{\text{edu}}]$$
$$+P_{42}\cdot\frac{S}{N_{\text{C}}}\cdot[\frac{Y_1}{Y_2}\cdot P_{21}\cdot R_{31}+P_{23}\cdot R_{32}+(1-P_{21}-P_{22}-P_{23})\cdot(1+P_5)\cdot R_1]-S\cdot R_1$$
$$=22.73-20.74=1.99\ (\text{million dollars})$$

Cost-effectiveness to consumers:

$$CE_{\text{cons,enh}} = \frac{EC_{\text{all,enh}}}{ER_{\text{enh}}}$$

$$= \frac{(1-P_{42})\cdot S\cdot[R_1+R_{21}+(1-P_{41})\cdot R_{22}+\frac{Y_1}{N_C}R_{\text{edu}}]+P_{42}\cdot\frac{S}{N_C}\cdot[\frac{Y_1}{Y_2}\cdot P_{21}\cdot R_{31}+P_{23}\cdot R_{32}+(1-P_{21}-P_{22}-P_{23})\cdot(1+P_5)\cdot R_1]-S\cdot R_1}{[1-\frac{(1-P_{42})\cdot(1-P_{41}\cdot P_{11})\cdot(1-P_{11}-P_{12})}{1-P_{11}-P_{32}}-\frac{P_{42}\cdot(\frac{Y_1}{Y_2}P_{21}+P_{23})\cdot(1-P_{11}-P_{12})}{1-P_{24}-P_{25}}-P_{42}\cdot(1-P_{21}-P_{22}-P_{23})]\cdot E}$$

$$= \frac{S}{E}\cdot\frac{(1-P_{42})\cdot[R_1+R_{21}+(1-P_{41})\cdot R_{22}+\frac{Y_1}{N_C}R_{\text{edu}}]+P_{42}\cdot\frac{1}{N_C}\cdot[\frac{Y_1}{Y_2}\cdot P_{21}\cdot R_{31}+P_{23}\cdot R_{32}+(1-P_{21}-P_{22}-P_{23})\cdot(1+P_5)\cdot R_1]-R_1}{1-\frac{(1-P_{42})\cdot(1-P_{41}\cdot P_{11})\cdot(1-P_{11}-P_{12})}{1-P_{11}-P_{32}}-\frac{P_{42}\cdot(\frac{Y_1}{Y_2}P_{21}+P_{23})\cdot(1-P_{11}-P_{12})}{1-P_{24}-P_{25}}-P_{42}\cdot(1-P_{21}-P_{22}-P_{23})}$$

$$= \frac{1.99}{0.220} = 9.07\ (\text{dollars/MTCO}_2\text{E})$$

Lifetime costs for a DIY vehicle:

$$C_{\text{L,enh}} = \frac{Y_{\text{adj}}\cdot C_{\text{all,enh}}}{N_V} = \frac{Y_{\text{adj}}}{Y_1}\cdot\{N_C\cdot[R_1+R_{21}+(1-P_{41})\cdot R_{22}]+Y_1\cdot R_{\text{edu}}\}$$

$$= \frac{9\times 22.73}{1.227} = 166.73(\text{dollars})$$

Annual revenue loss by small can industry:

$$RL_{\text{enh}} = P_{42}\cdot S\cdot R_1$$

$$= 0\%\times 1.595\times 13 = 0$$

Similar to Can Ban, the revenue loss could be offset to some extent by the increased sales from internet and out-of-state. But this factor is not taken into account since no data are available to break down the leakage.

Derivation of Independent Parameters

1. P_0

Both ARPI and SAE point out that not all small cans containing HFC-134a are sold to DIYers. ARPI estimates that 30% of the cans are sold to professional market (ARPI, 2008a).

In contrast, SAE supplies data that indicate that of all the HFC-134a used in MVACs in 2003, factory fill, 30-lb cylinders and small cans have shares of 30%, 39% and 31%, respectively (Atkinson, 2008a). 30-lb cylinders are apparently exclusively used by professional shops. But some shops also use small cans, which is about 3.5% of the total usage by professional shops (MACS, 2008). Thus, out of all the HFC-134a used in MVACs, the percentage of HFC-134a in small cans used by professional shops is 3.5% × [39% / (1 – 3.5%)] = 1.41%. This means that 1.41% / 31% = 4.6% of small cans are sold to professional shops. For the purpose in this analysis, we take the average of the two estimates, 17.3%, as the percentage of HFC-134a in small cans that are sold to professional shops in California. So the percentage of small cans sold to DIYers in California is 82.7%. Rounding it off results in 83%, as presented in the Table for Independent Parameters.

2. P_{24} and P_{25}

The GREEN-MAC-LCCP Model, Version 3, uses the following emission estimates on professional servicing (Papasavva et al., 2008): 35 grams per service for servicing leaks and 5 grams per service for heel emissions. According to Assumption 1, the effective charge during professional servicing is the same as that during DIY recharging. And the latter is

67% × 1.3 can / recharge × 12 oz / can × 28 g / oz = 293 g.

So the total amount of refrigerant used per professional servicing is:

35 + 5 + 293 = 333 (g),

in which servicing leaks, heel emissions and effective charge account for 10.5%, 1.5% and 88%, respectively. By rounding off the values, we use 10% and 2% for P_{24} and P_{25}, respectively.

Note that during recharging, a professional trained technician would first recover the refrigerant left in the A/C, then recharge the system with an appropriate amount (usually the nominal charge) of refrigerant. The recovered refrigerant would be either reclaimed onsite or sent to a recycling facility for proper recycling / reclamation. The concept of 'effective charge' used here for the calculation of P_{24} and P_{25} is not the total charge during recharging phase (usually the nominal charge), but rather the net charge of recovering and recharging phases (usually the same as the amount of refrigerant an A/C has to lose before a recharge takes place).